

Multi-Stage: A Rule-Based Evolution of Future Commitments Under the Climate Change Convention

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Abstract. This article presents the regional emission targets corresponding to different climate regimes for differentiating commitments beyond 2012 on the basis of the Multi-Stage approach. This approach assumes a gradual increase in the number of Parties involved and their level of commitment according to participation and differentiation rules. The analysis focuses on two global greenhouse gas emission profiles resulting in CO₂-equivalent concentrations stabilising at 550 and 650 ppmv in 2100 and 2150, respectively. Three Multi-Stage cases have been developed in order to assess different types of thresholds. These share three consecutive stages representing different commitments: stage 1 – no quantitative commitments; stage 2 – emission-limitation targets and stage 3 – emission reduction targets. The analysis shows that by 2025 all three cases result in emission reduction objectives for all Annex I regions of at least 30–55% below their 1990 levels for 550 ppmv, whereas for 650 ppmv target they range from 0 to 20%. Furthermore, early participation is required of the major non-Annex I regions through emission limitation targets i.e. before 2025 and 2050 for the 550 and 650 ppmv targets, respectively. The first participation threshold for adopting emission-limitation targets on the basis of a capability-responsibility index (as introduced here) can provide for a balanced and timely participation of non-Annex I regions. Major strengths and weaknesses of the climate regimes are discussed and important obstacles and pre-conditions for their feasibility and acceptability are highlighted.

Key words: differentiation of future commitments, international regime, Multi-Stage, post-Kyoto climate regime

Abbreviations: CDM – Clean Development Mechanism; CR – Capability-Responsibility; GHG – Greenhouse gas; PCC – Per Capita Convergence; UNFCCC – United Nations Framework Convention on Climate Change

1. Introduction

The Multi-Stage approach is one of the possible international climate regimes for differentiating emission targets for both Annex I and non-Annex I countries beyond

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2012. The approach divides countries into groups with different levels of effort and types of commitments (stages). The aim of such a system is to ensure that countries with similar circumstances in economic, developmental and environmental terms have comparable responsibilities, i.e. commitments under the climate regime. Moreover, the system defines when a country's level of commitment changes according to pre-determined rules taking modifications in its national circumstances into account.

The Multi-Stage approach thus results in an incremental evolution of the climate change regime, i.e. a gradual expansion over time of the group of countries with emission targets (the Annex I), with countries adopting different levels and types of commitments according to participation and differentiation rules. The various levels of participation could be organised in the form of building up different Annexes to the UNFCCC. The approach was first developed by Gupta (1998). Later, in Berk and den Elzen (2001) and den Elzen (2002) the approach was elaborated into a quantitative scheme for defining mitigation commitments under global emission profiles compatible with the UNFCCC objective of stabilising the atmospheric greenhouse gas concentrations at a level that would '*prevent dangerous anthropogenic interference with the climate system*'.

Criqui and Kouvaritakis (2000) proposed an alternative 'multi-grouping' regime, called Soft Landing. This approach encompasses a scheme for a progressive reduction of the growth in emissions of non-Annex I countries to zero with a time schedule to plan the moment of stabilisation of emissions differentiated on the basis of their per capita emissions and per capita income levels, as well as on their population growth.¹ Annex I countries keep reducing their emissions according to an 'extended Kyoto-type' trend (Blanchard et al. (2000, 2003).

In contrast to the Multi-Stage scheme, in the Soft-Landing scheme, all non-Annex I countries participate immediately after 2012, thus providing for early participation and a smooth transition in the emission pathways of non-Annex I countries. However, it does not result in the global emission reductions needed for stabilising greenhouse gas (GHG) concentrations, and lacks clear rules related to equity considerations in the UNFCCC. In the evaluation of both the Multi-Stage and Soft-Landing approach (see Criqui et al. 2003), the Multi-Stage scheme was found to provide a promising methodology for extending the present Kyoto protocol in a gradual but structured way, while the Soft-Landing approach contained interesting elements that might be incorporated. However, the original Multi-stage approach was considered to be rather complex, and therefore it was decided to reduce the number of stages and policy variables.

This article describes and analyses the regional emission targets² of a new, simplified MultiStage scheme that in contrast to the original proposal (Berk and den Elzen 2001) incorporates elements from the Soft-Landing approach and other improvements. In developing the new Multi-Stage variants, the aim was to construct regimes that would:

- account for various equity principles;
- result in a gradual shift from no emission control commitments to full participation in the emission–reduction stage via a transition stage, and
- be relatively simple, that is, based on a limited number of policy variables.

This has resulted in three distinct Multi-Stage cases, all of which have several features in common and other features that differ.

To assess the sensitivity of the regional targets to the different GHG concentration stabilisation levels, we have used two global GHG emission profiles in the analysis that result in a stabilisation of the CO₂-equivalent concentration³ at 550 and 650 ppmv in 2100 and 2150, respectively (Eickhout et al. 2003).⁴ Furthermore, results for an emission allocation case, which has been derived from the ‘Contraction & Convergence’ approach (Meyer 2000) and called Per Capita Convergence (PCC) here, have been added for comparison so as to put the outcomes of the Multi-Stage cases into perspective. The PCC approach assumes a convergence of per capita emission endowments from post-Kyoto levels to equal levels by 2050. This climate regime has been selected, among many others, for the sake of the comparison’s simplicity and because it is well known, transparent and generally well-accepted in the developing world (e.g. multi-criteria analysis of den Elzen et al. (2003)). For this analysis we used a Common POLES-IMAGE (CPI) baseline, which up to 2030 is largely based on the existing POLES model reference scenario (see Criqui and Kouvaritakis 2000), with an extension up to 2100 based on the IMAGE 2.2 model (IMAGE-team 2001), as described in detail in van Vuuren et al. (2003). The decision-support model FAIR 2.0 (Framework to Assess International Regimes for differentiation of future commitments) is used for the analysis of endowments (den Elzen and Lucas 2003; den Elzen et al. 2004b).⁵ The regional endowments (assigned amounts, or emission allowances; from this point on we will use the term ‘endowments’), baselines and emission profiles are all calculated in aggregate CO₂-equivalent emissions, calculated using the emissions of the six Kyoto gases combined with the 100 years Global Warming Potentials (GWPs) (IPCC 2001).

The features of the three Multi-Stage cases are described in more detail in Section 2. Section 3 presents the analysis of the implications of the cases in terms of the regional emission endowments. Section 4 presents the pros and cons of the three approaches, and Section 5 summarises our findings.

2. The New Multi-Stage Approach: Three Alternative Cases

2.1. EQUITY PRINCIPLES AND STAGES OF COMMITMENTS

Equity principles refer to general concepts of distributive justice or fairness. Many different categorisations of equity principles can be found in the literature (e.g., Rose 1998; Ringius et al. 1998, 2002). The equity principles were deemed important in designing the simplified Multi-Stage approach. In any attempt of this kind, there has to be a clear story relating the regime design to various equity considerations.

Ringius et al. (2002) in search for the politically most salient equity principles for distributive fairness, conclude that three principles stand out as the most relevant elements for a widely accepted regime to target differentiation in future international climate negotiations:⁶

- *Need*: Mitigation efforts or emission ceilings should leave room to eradicate poverty and attain a reasonable standard of living or, in other words, should respect the equal rights of humans to develop.
- *Capability*: mitigation efforts should be distributed in proportion to each country's ability to pay and to its mitigation opportunities.
- *Responsibility*: mitigation efforts should be distributed in proportion to a country's share of responsibility for causing the problem.

These equity principles are largely reflected in the different stages within the new Multi-Stage approach below:

- *Stage 1* (no commitments) – corresponds with securing basic needs by exempting the least developed countries from quantitative commitments and allowing them to follow their unconstrained emission-path;
- *Stage 2* (emission limitation compared to the unconstrained path) – corresponds with contributing according to each party's capability (and avoiding disproportional burdens), and allows for a transition towards a full contribution.
- *Stage 3* (emission reduction in absolute terms) – corresponds with contributing according to each party's responsibility by allocating the emission reduction based on its contribution to climate change.

2.2. QUANTITATIVE SCHEME OF THE THREE MULTI-STAGE CASES

This concept has been converted into the following operational schemes for defining three Multi-Stage cases (Multi-Stages A, B and C), based on the definition of the three consecutive stages, i.e.:

- *Stage 1*. No quantitative commitments. Non-Annex I regions follow their unconstrained emission path.
- *Stage 2*. Emission (growth) limitation targets. The non-Annex I regions adopt intensity improvement targets (Multi-Stages A and B), or follow a prescribed slow-down in the emissions growth to stabilisation (Multi-Stage C).
- *Stage 3*. Emission reduction targets. Here the total reduction effort⁷ to achieve the global emission profile is shared among all participating regions on the basis of a burden-sharing key (here per capita emissions).

All Annex I regions (including the US⁸) are assumed to be in Stage 3 after 2012. The different thresholds and transition process are defined below (see Table I).

- *To Stage 2: from no-commitments to emission-limitation (emission intensity) targets*
The transition from Stage 1 to 2 depends, for all Multi-Stage cases considered here, on a Capability–Responsibility (CR) index. The CR-index originates in the

Table I. The main characteristics of the three Multi-Stage cases.

	Multi-Stage A ("dynamic threshold")	Multi-Stage B ("double CR-threshold")	Multi-Stage C ("transition path")
<i>Stage 1</i> No commitments			
<i>Stage 2</i> Emission-limitation targets			
First threshold (to Stage 2)	Capability-Responsibility (CR) index	Same as Multi-Stage A	Same as Multi-Stage A
Emission-limitation targets	Income-dependent improvement of intensity targets	Same as Multi-Stage A	Prescribed emission stabilisation profile
<i>Stage 3</i> Emission-reduction targets			
Second threshold (to Stage 3)	Percentage of world-average per capita emissions	CR-index value	–
Absolute targets, reductions proportional to burden sharing key	Per capita emissions	Same as Multi-Stage A	Same as Multi-Stage A

principles used by Criqui and Kouvaritakis in the Soft-Landing approach. In practical terms, it can be defined as the sum of the per capita income (expressed in PPP€1000 per capita)⁹, which relates to the capability to act, and of the per capita CO₂-equivalent emissions (expressed in tCO₂ per capita), which reflects the responsibility in climate change.

Because it combines variables of a different nature, this composite index should in principle be normalised or weighted. It happens however that, although a more sophisticated method of normalisation would make the index 'unitless', the one-to-one weighting already produces simple and satisfactory results. On any date, the index can thus be computed as the sum of GDP and of total GHG emissions, and divided by the population of the region or country considered (Criqui et al. 2003), as illustrated in Table II.

Despite its origin in a pragmatic approach, this indicator shows good 'screening' properties, in the sense that it allows a satisfactory reproduction of the existing Annex I, as well as relevant country groupings for non-Annex I regions. The ranking of regions, resulting from the 2000 index, is modified in 2025 for only a limited number of cases, in particular China and the Southern African region.

Compared to a single capability-oriented threshold, like per capita income in the original Multi-Stage approach (Berk and den Elzen 2001), the CR-index

Table II. The CR-index in 2000 and 2025, regions ranked by decreasing value in 2000.

	2000			Baseline – 2025		
	Per Capita GDPP (1000€, PPP)	+ Per Capita Emissions (tCO ₂ e)	= CR Index ^a	Per Capita GDPP (1000€, PPP)	+ Per Capita Emissions (tCO ₂ e)	= CR Index
USA	32	26	58	46	27	73
Canada	26	21	47	38	21	59
Oceania	19	17	35	31	17	48
Japan	25	10	35	38	12	50
Enlarged EU	19	10	29	33	12	45
CIS + Other Europe	5	10	16	12	16	28
Middle East	5	6	12	10	8	18
Latin America	7	5	11	11	6	17
South East Asia	4	3	8	10	6	16
China	4	4	8	11	7	18
Africa	2	2	4	3	3	5
India	2	2	3	6	4	10
Rest South Asia	2	1	3	3	2	5

^a Index may differ from the sum due to independent rounding.

Source: POLES model.

generally tends to result in an earlier participation of low-income countries, in particular, those that have relatively high per capita emission levels. On the basis of the experience with the Soft Landing approach, proper weighting of both Capacity and Responsibility factors can prevent too poor countries having to participate early onwards.

In Stage 2, the Multi-Stages A and B cases share GDP-related emission intensity targets. More specifically, the GHG emission intensity improvement rate is defined as a linear function of per capita income level IC (in PPP€ per capita), i.e.: $\max[a \times IC_R(t), EIR_{\max}]$, where t is the year of calculation, a , a coefficient and $EIR_{\max}$, the exogenous ‘maximum de-carbonisation rate’. The latter is adopted to avoid de-carbonisation rates that would outpace those of economic growth and result in absolute reduction targets for middle-income countries. The basic idea behind the coefficient a is that the intensity improvement rate reaches a maximum at 50% of the (1990) Annex I income, where the corresponding income level is $IC_{\max}$ in PPP€ per capita; it can be calculated as $EIR_{\max} / IC_{\max}$.

The Multi-Stage C case provides a prescribed emission–limitation growth target for Stage 2, leading to a stabilisation of emissions, as in the Soft-Landing approach. The length of this stabilisation period is calculated by dividing the transition constant TC by the per capita emission level (in tCO₂-equivalent per capita) when the

first CR-threshold is met. For example, if the transition constant is 70, a region with per capita emissions of 5 tCO₂-equivalent will have to bring down its emission growth rate to zero in 14 years.¹⁰

• *To Stage 3: from emission-limitation to reduction targets*

The three Multi-Stage cases differ only with respect to the transition from Stage 2 to 3, i.e. from dynamic emission (growth) limitation targets to absolute emission reduction targets.

- In Multi-Stage A the entry to Stage 3 depends on a threshold that is defined as a proportion of the world average per capita emission level.
- Multi-Stage B uses again a CR-index, with a value that is about twice the one used for the Stage 1–2 threshold.
- In Multi-Stage C the entry to Stage 3 begins after the period of stabilisation has ended.

The dynamic threshold of Multi-Stage A, i.e. the world-average per capita emission, accommodates the change over time in the average per capita emission levels. This has two advantages: (1) it ensures timely participation of developing countries to keep total emissions below a global emission ceiling for meeting stabilisation targets, and (2) it rewards Annex I action by bringing the threshold-level down (see Section 3). Compared to the original Multi-Stage approach (Berk and den Elzen 2001), the dynamic threshold is extended by adding a factor that defines the threshold level as a percentage of the world average. This largely preserves the above-mentioned advantages, while temporarily allowing developing countries per capita emission levels higher than the world average.

All Multi-Stage cases assume the same burden-sharing key in Stage 3, based on per capita emissions.¹¹ This key tends to result in some convergence in the per capita emission levels, as mentioned in the pre-amble of the Marrakech Accords.¹²

2.3 ADJUSTING THE KEY PARAMETERS TO THE GLOBAL EMISSION PROFILES

The levels chosen for the different thresholds and the rules applied to the entry in each stage have to be differentiated according to the global emission profile. Table III provides a description of the parameter setting for the two profiles (see Section 3.1) resulting in a stabilisation of the CO₂-equivalent concentration at 550 and 650 ppmv (hereafter referred to as S550e and S650e), respectively. Under the S650e profile, there is less need for non-Annex I regions to contribute to global emission control. Therefore, the different parameters have been significantly relaxed, as compared to their values in the much more stringent S550e profile. The thresholds for the CR-index are higher, the maximum value for the de-carbonisation rate lower, and the stabilisation periods are longer. Section 3 provides a background for the chosen parameter values.

Table III. Assumptions for policy variables the Multi-Stage cases for the S550e and S650e profile.

Key parameters	Multi-Stage A	Multi-Stage B	Multi-Stage C
First threshold	S550e: CR ^a = 5 S650e: CR = 12	Same as Multi-Stage A	Same as Multi-Stage A
Emission-limitation targets	Intensity targets S550e: max = 3.0%/yr ^c S650e: max = 2.5%/yr ^c	Same as Multi-Stage A	S550e: TC ^b = 70 S650e: TC = 100
Second threshold	Percentage of world-average pc emissions S550e: 100% S650e: 120%	S550e: CR = 12 S650e: CR = 20	–
Burden-sharing	Per capita emissions	Same as Multi-Stage A	Same as Multi-Stage A

^a Capability–Responsibility (CR) index.

^b Transition Constant (TC).

^c The de-carbonisation rate reaches a maximum at 50% of (1990) Annex I income (about PPP€1000 per capita per year).

3. Analysis of the Multi-Stage Cases

3.1. S550e AND S650e PROFILES

This section analyses the regional emission endowments resulting from the Multi-Stage approaches for post-Kyoto commitments till 2050, for the two global emission profiles S550e and S650e. For the short term (up to 2010), the profiles incorporate: (i) implementation of the Annex I Kyoto Protocol targets, (ii) a revenue maximising level of banking surplus emissions by the Former Soviet Union (FSU) and Eastern Europe, and (iii) adoption of the greenhouse gas intensity target for the USA (–18% between 2002 and 2012) (White-House 2002). Non-Annex I countries are assumed to follow their baseline emissions until 2012. These assumptions are important in defining the initial situation for the analysis, i.e. the regional emission levels by 2012.

Figure 1 shows the two emission profiles, indicating that under the S550e profile in 2025 the global CO₂-equivalent emission levels can still increase to 20% above 1990 levels, but that this implies already a substantial reduction of 30% compared to baseline levels. In 2050, the emissions have to be reduced strongly, not only compared to baseline level (65%), but also compared to 1990 (about 15%). For the S650e profile reductions compared to the baseline in 2025 are lower (15%). The GHG emission levels can still be 50% above 1990 by 2050, but compared to the baseline, they will need to be reduced by about 35%.

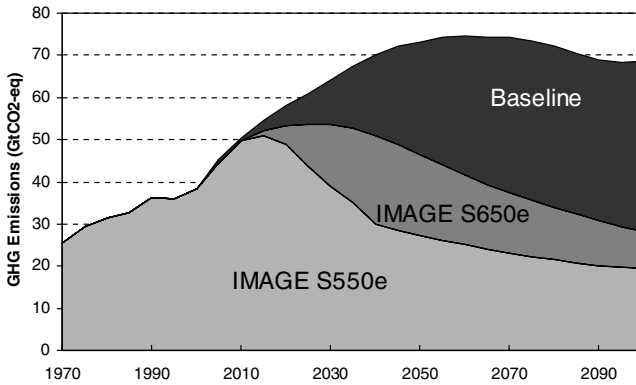


Figure 1. Global emission profiles for stabilising GHG concentrations at 550 and 650 ppmv CO_2 -equivalent (Eickhout et al. 2003).

3.2. THE MULTI-STAGE CASES FOR THE S550e PROFILE

The parameter values for the Multi-Stage cases and the S550e profile (as listed in Table III) were selected on the following grounds: the resulting scheme should (i) meet the global emission profile; (ii) ensure timely participation of the non-Annex I regions; (iii) provide some convergence in the per capita emissions for the Annex I and non-Annex I regions before 2050. For more details, we refer to den Elzen et al. (2004a). Appendix A presents an analysis of the robustness of the results for these parameter settings. The same first CR-threshold of 5 is chosen for all three Multi-Stage cases under the S550e profile. The Multi-Stage A case assumes the world average per capita emissions as the second participation threshold for the emission reduction stage, resulting in a gradual convergence of per capita endowments between Annex I and non-Annex I regions over time (see Figure 2). The East Asia (China) region plays a key role in this outcome. When East Asia enters the emission reduction regime, its emission endowments will have to decrease considerably, thereby relaxing the emission reductions for the other participating regions. For this reason, East Asia's entry strongly determines the reduction efforts of the Annex I countries.

A similar convergence in per capita emissions is found for Multi-Stage B with a second CR-threshold of 12. Higher CR-values delay mainly the participation of the major non-Annex I regions (in particular China), thereby increasing the Annex I reduction efforts. A lower CR-value would imply the early participation of the middle-income non-Annex I regions, especially Central America and East Asia, which may not be realistic. For the Multi-Stage C case a value of 70 was chosen for the TC as this results in a convergence in the Annex I and non-Annex I per capita emissions by 2040.

Figure 3 depicts the change in the ratio of endowments to the 1990 level for 10 aggregated regions and 2 time horizons, short-term (2025) and long-term (2050).

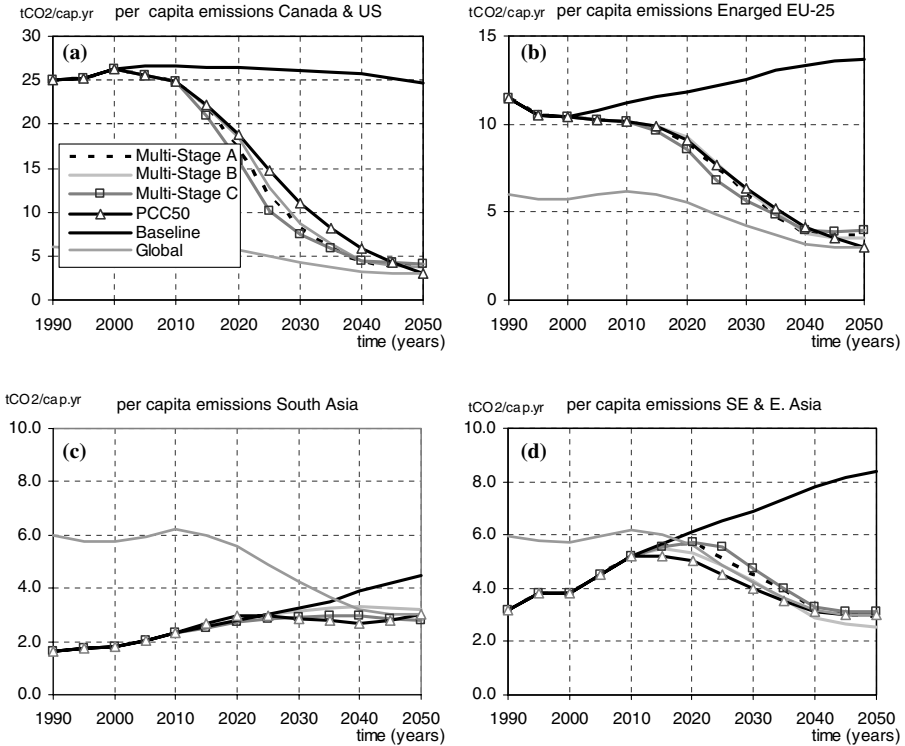


Figure 2. Per capita emission endowments for the Multi-Stage cases and the Multi-Stage cases and PCC50 (Per Capita Convergence 2050) case for the S550e profile for Canada and US (a), EU-25 (b), South-Asia (c) and South-East and East Asia (d). The bold grey line represents the global per capita emissions. For South Asia the Multi-Stage A outcomes are the same as the Multi-Stage B outcomes, and for South-East and East Asia the same holds for the PCC50 case.

Regional endowments can also be compared with the corresponding baseline emissions, providing more information on the magnitude of actual effort required from the different Parties. Therefore, Table V provides both ratios of reduction.

- *Timing for participation of non-Annex I regions* – For the emission-limitation stage most non-Annex I regions participate in as early as 2012, while South Asia and Western and Eastern Africa enter in this stage after 2050 (see Table IV). For the emission-reduction stage, for the middle- and high-income non-Annex I regions, Multi-Stage B leads to the earliest entry for in this stage, whereas the Multi-Stage C case shows the latest entry. For the low-income non-Annex I regions, all three Multi-Stage cases show late entry, especially Multi-Stages B and C (Table IV). For the low-income region Southern Africa, there are notable differences in the entry dates. Due to its relatively high per capita emission level, this region participates early in Stage 3 in the Multi-Stage A case (emission trigger) and Multi-Stage C

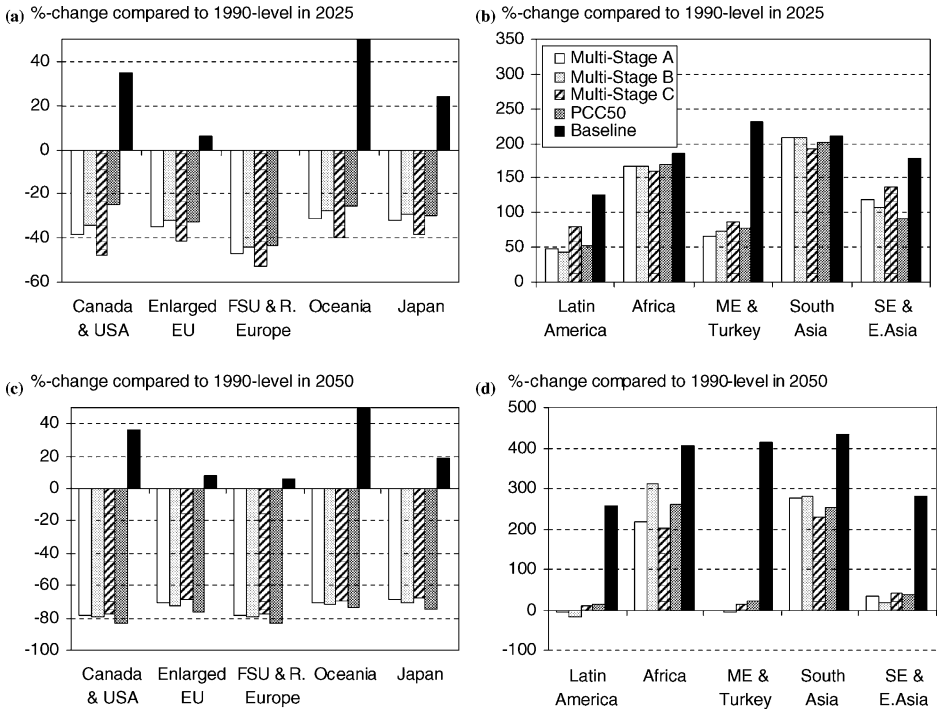


Figure 3. Percentage change in the CO₂-equivalent emission endowments relative to the 1990 emissions level for the Multi-Stage and PCC50 cases in 2025 (a and b) and 2050 (c and d) for the S550e profile.

case (short transition period). Conversely, the CR-threshold in Multi-Stage B delays the participation in Stage 3.

- *Comparing emission allocations* – For the Annex I regions, the total endowments are the highest in Multi-Stage B, whereas Multi-Stage C shows the lowest levels, which is the direct consequence of the early and late entry to Stage 3 of the middle- and high-income non-Annex I regions, respectively. These regions show the opposite pattern, with the lowest reductions in Multi-Stage C. Again the East Asia region plays a key role in the Multi-Stage outcomes, since when East Asia enters the emission-reduction stage, it considerably relaxes the reductions for the other participating regions, i.e. Annex I. For the low-income non-Annex I regions, the Multi-Stage C case is, in general, the regime with the strongest constraints due to higher reductions in the emission-limitation stage. For the Southern Africa region, the differences in the entry-dates for Multi-Stage cases explain the wide range in outcomes.
- *Annex I and non-Annex I targets* – By 2025, the endowments for all Annex I regions need to be 30–55% below their 1990 levels, whereas non-Annex I regions can still increase their emissions compared to 1990 levels. Nevertheless, the non-Annex I regions do have to reduce their emissions compared to the baseline levels. The reductions are more differentiated across non-Annex I regions than across

Table IV. S550e profile, entry-dates of non-Annex I regions in Stages 2 and 3.

Regions	Central America	South America	North Africa	West Africa	East Africa	South Africa	Middle East	South Asia	East Asia	South-East Asia
Entry into Stage 2	2012	–	2012	2055	2065	2012	–	2015	2012	2010
Entry into Stage 3										
Multi-Stage A	2035	2012	2040	2060	2075	2030	2012	2045	2020	2035
Multi-Stage B	2015	2012	2050	2100	2100	2060	2012	2050	2015	2030
Multi-Stage C	2025	2025	2030	2085	2095	2030	2020	2045	2025	2030

For each region, white-boxes indicate the earliest entry case, dark-grey the latest and light grey in between. South America and Middle East directly enter into Stage 3 after Kyoto.

Table V. Reductions for the Multi-Stage cases and PCC50 (Per Capita Convergence 2050) case in 2025 and 2050 for the S550e profile.

S550e profile	2025				2050			
Regions	Multi- Stage A	Multi- Stage B	Multi- Stage C	PCC50	Multi- Stage A	Multi- Stage B	Multi- Stage C	PCC50
<i>(a) Compared to baseline emissions</i>								
USA	54	51	61	43	84	85	83	88
Canada	57	55	62	53	82	83	81	85
OECD Europe	40	37	46	38	73	74	72	78
Eastern Europe	33	30	39	31	71	73	70	77
Former USSR	47	44	53	44	80	81	78	85
Oceania	55	53	61	51	83	83	82	85
Japan	45	43	50	44	74	75	73	78
Central America	25	34	20	29	65	74	67	63
South America	39	37	20	33	77	78	71	70
Northern Africa	12	12	11	19	42	36	57	46
Western Africa	0	0	0	-13	0	0	0	-8
Eastern Africa	0	0	0	-44	0	0	0	-40
Southern Africa	9	9	17	32	70	28	72	66
ME & Turkey	49	48	43	46	81	82	78	76
South Asia	1	1	6	3	29	29	38	33
SE & E.Asia	21	26	15	31	65	69	63	64
World	32	32	32	32	64	64	64	64
<i>(b) Compared to 1990 emissions</i>								
USA	39	34	48	24	79	80	77	84
Canada	40	37	48	35	75	77	74	79
OECD Europe	34	31	41	32	70	72	69	76
Eastern Europe	37	34	43	35	71	73	70	77
Former USSR	47	44	53	44	79	80	77	84
Oceania	32	28	40	26	71	72	69	74
Japan	32	29	38	30	69	71	67	74
Central America	-63	-43	-74	-53	-19	13	-10	-24
South America	-40	-44	-84	-53	16	18	-7	-8
Northern Africa	-138	-138	-139	-117	-135	-158	-74	-117
Western Africa	-240	-240	-240	-286	-466	-466	-466	-513
Eastern Africa	-135	-135	-135	-239	-291	-291	-291	-446
Southern Africa	-154	-154	-131	-88	-73	-318	-63	-98
ME & Turkey	-67	-73	-87	-78	3	6	-12	-23
South Asia	-208	-208	-191	-200	-278	-279	-231	-255
SE & E.Asia	-119	-107	-137	-92	-34	-17	-41	-36
World	-22	-22	-22	-22	15	15	15	15

Annex I regions (see Table V). The low-income non-Annex I regions (African regions and South Asia), experience small emission constraints in all Multi-Stage cases, with emissions close to their baseline (less than 10–20% reduction). However, the middle- and high-income non-Annex I regions (Latin America, the Middle East and South East & East Asia) hold an intermediate position.

The differences for the Annex I regions in 2050 are relatively small, as all Multi-Stage cases lead to very low endowments (70–85% below 1990 levels). The middle- and high-income non-Annex I regions experience similar levels of reduction compared to their baseline emissions (see Table V). For the low-income non-Annex I regions, the reductions compared to the baseline emissions are still less compared to the other regions, but already reach percentages of 30–40% for South Asia, and 30–70% for Northern and Southern Africa; only Western and Eastern Africa still follow their baseline emissions.

- *Comparing emission allocations with the PCC50 case* – In comparing the Multi-Stage cases with the per capita convergence 2050 (PCC50) case, the results appeared broadly comparable. However, short-term reductions of the Multi-Stage cases for the Annex I regions are relatively greater than under the PCC50 case, in particular for the US (see also Figure 2). The PCC50 case results in higher emission reduction for South-East & East Asia regions, since their high per capita emissions are close to the world average. Western and Eastern Africa benefit from their surplus emissions in the convergence case, which given the baseline and the S550e profile, does not lead to significant amounts.

3.3. MULTI-STAGE CASES FOR THE S650e PROFILE

Table III provides an overview of the assumptions made in implementing the various Multi-Stage variants under the S650e profile. All Multi-Stage cases again use the same assumptions for the following policy variables: (i) first participation threshold, (ii) linear de-carbonisation rate, and (iii) burden-sharing key (e.g., den Elzen et al. 2004a). The S650e profile corresponds to a significantly less severe constraint and results in a very different timing for the implementation of emission targets. Therefore, the values of the settings are different from the S550e profile. As early participation of non-Annex I regions and very stringent intensity improvements are no longer necessary, the first CR-threshold level has been relaxed to 12 and the maximum de-carbonisation rate has been reduced to 2.5% per year. This results in a sufficiently early participation of middle- and high-income non-Annex I regions in Stage 3, while still leaving them some time in the transition stage.

The Multi-Stage A case assumes a threshold of 120% of world average per capita (CO₂) emissions for participation in the emission reduction regime. This results in some convergence of Annex I and non-Annex I per capita emissions over time, but not before 2050. Under a higher threshold level, the non-Annex I regions per capita emissions would exceed the Annex I per capita emission levels. For Multi-Stage B, the same assumptions are made, except for the participation threshold for the emission reduction stage, which is now based on a CR-threshold of 20. Lowering the CR-value reduces the Annex I reduction efforts, but results in a short emission-limitation stage for non-Annex I regions. Higher CR-values delay the participation of the middle-income non-Annex I regions and lead to high Annex I reduction

efforts. For the Multi-Stage C case, we used a TC value of 100 to extend the stabilisation period for the non-Annex I regions, and thereby reduce their reduction efforts under this profile.

- *Timing for participation of non-Annex I regions* – For the emission limitation stage, most middle – and high income non-Annex I regions show similar early entry dates as under S550e (in the second commitment period), but SE Asia ten years later, and also North- and East Africa 30 years later. For the emission reduction stage, the middle- and high-income non-Annex I regions participate much later than in the S550e profile, although still before 2040. Conversely, the low-income non-Annex I regions show a very late entry in Stage 2, which occurs only by 2050 for South Asia, and after 2100 for Western and Eastern Africa (Table VI). Due to the late entry of the non-Annex I regions, most of the reductions in 2025 come from the Annex I regions.
- *Comparing emission allocations* – The entry date of East Asia in the reduction stage again plays a key role for the future Annex I reduction efforts. The Multi-Stage C case with the earliest entry of East Asia yields the lowest efforts; the opposite holds for Multi-Stage B. For some middle- and high-income non-Annex I regions, e.g. the Middle East, the Multi-Stage A case is clearly the most stringent, because entry to the emission reduction stage is almost immediate. Multi-Stage C provides higher emissions for these regions as it allows for a longer transition period (Figure 4). For the low-income non-Annex I regions, there are almost no differences in the outcomes for the three Multi-Stage cases, since these regions do not participate before 2050. For the Annex I regions, Multi-Stage A provides higher emissions in both the short and the long term due to the above-mentioned earlier participation of the richest non-Annex I regions in Stage 3.
- *Annex I and non-Annex I targets* – In 2025, the endowments result in reductions from baseline that are less pronounced, and also show a wider range (Table VII). This range varies from a growth of 10% for the US to 30% reduction compared to 1990 levels for the FSU. Most non-Annex I regions hardly have to limit their emissions in 2025, as the African regions and South Asia are no longer constrained in the Multi-Stage cases. Reductions are limited to 5–10 % for South-East and East Asia, 5–20% for Latin America and 20–40% for the Middle East.
In 2050, the Annex I emissions are 40–60% below 1990 levels, resulting in a reduction of 45–70% compared to the baseline levels. The low-income non-Annex I regions have very low required reductions compared to their baseline. In the other non-Annex I regions, the reductions compared to the baseline emissions remain globally lower than for Annex I, with 40, 50 and 60%, respectively, for South-East and East Asia, Latin America and the Middle East.
- *Comparing emission allocations with PCC50 case* – For the low-income non-Annex I regions, the PCC50 case yields by far the highest endowments. In this higher global emission profile, it even translates into many more surplus emissions compared to the baseline, for all African regions (except South Africa) and also

Table 1/1. S650e profile, entry-dates of non-Annex I regions in Stages 2 and 3.

Regions	Central America	South America	North Africa	West Africa	East Africa	South Africa	Middle East	South Asia	East Asia	South-East Asia
Entry into Stage 2	2015	2012	2040	—	—	2040	2012	2050	2015	2025
Entry into Stage 3										
Multi-Stage A	—	—	2090	—	—	2045	2012	—	2045	—
Multi-Stage B	2055	2045	2075	—	—	—	2045	2080	2040	2050
Multi-Stage C	2035	2030	2065	—	—	2060	2025	2075	2035	2050

For each region, white-boxes indicate the earliest entry case, dark-grey the latest and light grey in between.

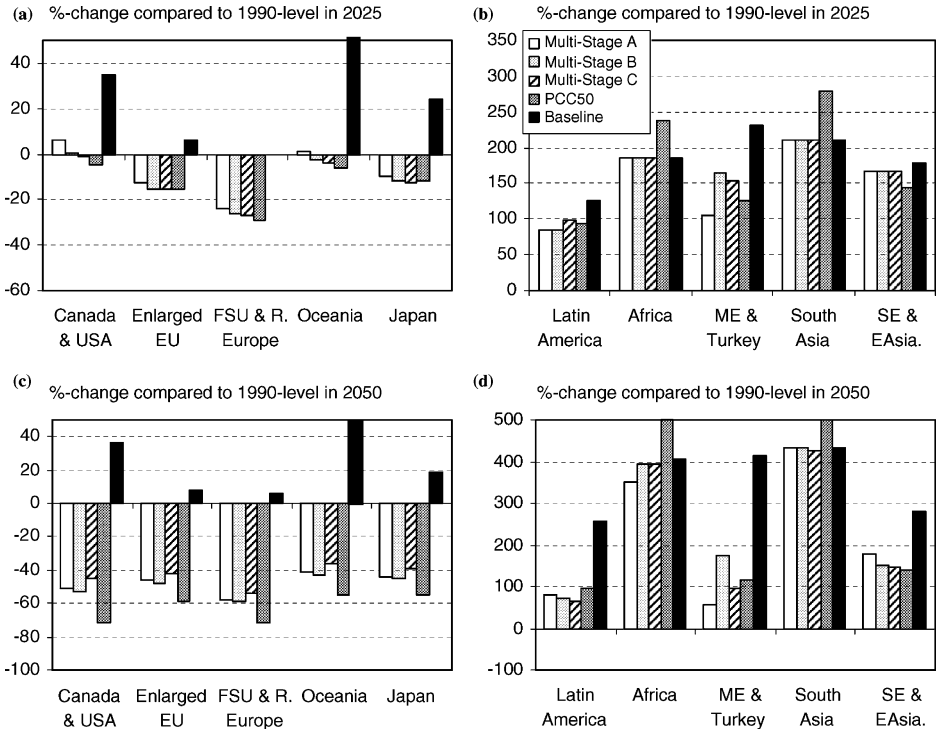


Figure 4. Percentage change in the CO₂-equivalent emission endowments relative to the 1990 emissions level for the Multi-Stage and PCC50 cases in 2025 (a and b) and 2050 (c and d) for the S650e profile.

for South Asia. In order to compensate for these surplus emissions, the PCC50 case now results in emissions for the Annex I regions that are lower than in the Multi-Stage cases. The PCC50 case becomes the most stringent scheme for them. The PCC50 remains the most stringent case for the South-East and East Asia region, since their per capita emissions are close to the world average. For Latin America and the Middle East, the differences between the Multi-Stage cases and PCC50 case are small, except for Multi-Stage A, with high reductions for the Middle East.

4. Pros and Cons of the Multi-Stage and Per Capita Convergence Cases

In the previous sections we analysed and compared the implications of the Multi-Stage and Per Capita Convergence cases quantitatively. Here, we will evaluate the pros and cons of the three Multi-Stage variants and the PCC variant qualitatively.

Table VII. Reductions for the Multi-Stage cases and PCC50 (Per Capita Convergence 2050) case in the year 2025 and 2050 for the S650e profile.

S650e profile	2025				2050			
Regions	Multi- Stage A	Multi- Stage B	Multi- Stage C	PCC50	Multi- Stage A	Multi- Stage B	Multi- Stage C	PCC50
<i>(a) Compared to baseline emissions</i>								
USA	20	24	26	28	64	66	60	79
Canada	36	39	39	41	64	65	61	74
OECD Europe	19	21	22	22	51	52	46	63
Eastern Europe	12	14	15	13	48	50	44	60
Former USSR	24	26	27	29	60	61	56	73
Oceania	34	36	37	39	65	66	62	73
Japan	27	29	30	29	53	54	49	62
Central America	16	16	7	11	46	46	47	36
South America	20	20	14	16	51	53	56	48
Northern Africa	0	0	0	-2	12	12	6	6
Western Africa	0	0	0	-43	0	0	0	-89
Eastern Africa	0	0	0	-82	0	0	0	-143
Southern Africa	0	0	0	15	20	1	3	41
ME & Turkey	38	20	23	32	70	46	62	58
South Asia	0	0	0	-22	0	0	1	-16
SE & E.Asia	5	5	4	13	27	34	35	38
World	14	14	14	14	37	37	37	37
<i>(b) Compared to 1990 emissions</i>								
USA	-8	-2	0	4	51	54	45	72
Canada	12	15	16	18	50	52	46	64
OECD Europe	12	14	15	14	46	47	41	59
Eastern Europe	17	19	19	18	48	50	44	59
Former USSR	24	26	27	29	58	59	53	72
Oceania	-1	3	4	6	41	43	36	55
Japan	10	12	12	12	44	45	39	55
Central America	-83	-83	-102	-94	-83	-83	-79	-116
South America	-85	-85	-97	-93	-80	-71	-61	-88
Northern Africa	-169	-169	-169	-175	-254	-254	-280	-278
Western Africa	-240	-240	-240	-387	-466	-466	-466	-968
Eastern Africa	-135	-135	-135	-328	-291	-291	-291	-851
Southern Africa	-179	-179	-179	-138	-363	-478	-466	-245
ME & Turkey	-106	-166	-153	-125	-56	-175	-96	-115
South Asia	-211	-211	-211	-279	-431	-431	-427	-518
SE & E.Asia	-166	-166	-167	-143	-180	-151	-148	-138
World	-54	-54	-54	-54	-48	-48	-48	-48

4.1. MULTI-STAGE VARIANTS

The pros and cons of the three Multi-Stage variants from a technical and policy point of view are summarised here.

First, all variants share the same CR-index threshold for entering the emission-limitation stage. This threshold goes somewhat against the principle of need, as it is not solely based on the income level. However, it provides a happy medium between the principle of need (justifying that countries are being exempted) and the desirability of early entry of developing countries into the emission-limitation stage, so as to adjust to the overall stringency of the targeted profile. Moreover, it also allows for a more cost-effective global emission control via international emission trading (IET) (compared to the CDM mechanism),¹³ as we assume that for the Multi-Stage variants, regions can only participate in IET after having reached the first threshold, while before this, they can only participate in CDM. This may even make early participation attractive if it results in net benefits for the developing countries. For this to work in practice, however, sufficient institutional and technical capabilities will be required, in particular, with respect to the monitoring of national emissions. This is likely to be a key challenge for an early participation of developing countries in emission trading.

As far as the commitments in the emission-limitation stage are concerned, there is a key difference between the dynamic intensity targets in Multi-Stage A or Multi-Stage B and the limited growth targets in Multi-Stage C. The simulation results show the Multi-Stage C approach to allocate more emissions to the most developed non-Annex I regions than the Multi-Stages A and B cases do. Nevertheless, the dynamic intensity targets of the latter cases have the advantage of accounting for baseline uncertainty about economic growth. Conversely, fixed targets do not account for unexpected baseline developments; this could result in much higher economic costs for some countries. Since developing countries experience particularly large fluctuations in economic performance, they are likely to be more willing to adopt dynamic than fixed targets. At the same time, intensity targets do have drawbacks as well (de Moor et al. 2002), as they introduce uncertainties about the environmental effectiveness¹⁴ and complicate the measurement of the performance and thus the use of the emission-trading instruments. However, intensity targets appear to provide a better chance than fixed targets for involving developing countries at an early stage. Moreover, some of the drawbacks may be overcome by more sophisticated arrangements, like dual-intensity targets (Kim and Baumert 2002), indexed absolute targets (Philibert and Pershing 2001) or by inclusion of clauses to deal with risks resulting from situations of economic downfall.

The Multi-Stage C case has the advantage that it helps to create a rather smooth shift from the emission-limitation stage to the emission-reduction stage by first stabilising each Party's endowments. The Multi-Stages A and B cases may indeed result in some drastic shift from increasing emissions in the emission-limitation stage to decreasing emissions in the emission-reduction stage. Although the link between the length of the transition period and the per capita emission level in the reference period seems quite defensible from an equity perspective, the Multi-Stage C Transition Constant remains a somewhat artificial (dimensionless) parameter. It is neither directly related to per capita emissions (responsibility) nor to income

(capability). From a policy point of view, the abstract nature of the TC makes it probably less suitable for negotiations. However, the Multi-Stage C case may still be workable when negotiations focus on the principle of relating the length of the transition period to per capita emission levels and derive the TC level from negotiations on the overall stringency of emission control.

The main difference between the Multi-Stages A and B cases is the use of a dynamic threshold versus a fixed threshold for the emission–reduction stage. The dynamic world-average per capita emission threshold of Multi-Stage A can result in an early entry of relatively poor countries with high per capita emission levels (Southern and Northern Africa and the Middle East) in the emission–reduction stage, leading to relatively large emission reductions and possibly hardly acceptable burdens. On the other hand, it rewards Annex I action, provides an incentive for non-Annex I countries to keep below this threshold and makes the regime more robust for future adjustment of climate targets. The double Capability–Responsibility index approach in Multi-Stage B presents more evenly distributed emission reductions across the non-Annex I regions, because it involves early participation for most of them (somewhat delayed for the relatively poor ones with high per capita emissions). The Multi-Stage C variant provides for smooth transition pathways to the emission–reduction stage, but this makes the approach also less flexible and results in large Annex I emission reductions.

Finally, this assessment shows that some regions (Oceania, US, Canada, FSU and Middle East on the short term; and Northern and Southern Africa on the long term) will face large emission reduction burdens under the per capita emission burden-sharing key. Appendix A shows the outcomes to be quite sensitive to assumptions about this burden-sharing key in Stage 3. In the design of Multi-Stage systems, it may thus be necessary to allow for simple adjustment factors in the burden-sharing key, in order to avoid disproportional burdens and make these regimes acceptable for all Parties. One option to be further explored would be to make not only the thresholds, but also the burden-sharing key related to both per capita income and per capita emissions (capability), i.e. to some kind of Capacity–Responsibility rule, in order to reach a more balanced distribution among all Parties.

4.2. The PROS AND CONS OF THE MULTI-STAGE AND PCC CASES COMPARED

The main strengths of the PCC approach are its simple and transparent definition, the certainty it provides about the environmental effectiveness, the developing countries' participation and finally, the cost-effectiveness resulting from global participation in emission trading right from the start. At the same time, early participation of especially the least developed countries may cause implementation problems. These countries lack the institutional capacity to properly implement policies and monitor emissions (Baumert et al. 2003). This, in turn, will make them ineligible to participate in emissions trading. Another drawback of the approach is

Table VIII. Pros and cons of the Multi-Stage and per capita convergence approaches.

	Pros	Cons
Per capita convergence	Simple, transparent, easy to understand Offers incentives for some developing countries to participate because they are granted emission allowances. The least developing countries (LDCs) receive 'surplus' allowances that they can sell in a trading system. High cost-effectiveness due to full participation from the start Certainty about environmental effectiveness	Implementation problems, especially for the LDCs (emissions registration system, monitoring) Entails major financial transactions between North and South (emission trading, surplus emissions) Risk of surplus emissions resulting in extra costs for Annex I/middle-income developing countries (DCs) Political resistance against the resource-sharing concept. The approach is particularly unattractive to countries with high per capita emissions. DCs with relatively high per capita emissions will face early constraints in emissions. Rigid – cannot accommodate national circumstances Takes no account of other equity principles (capacity, responsibility for historical emissions)
Multi-Stage	Approach covers different equity principles Flexible concept with many degrees of freedom for adjusting commitments to national capabilities and offering room for negotiation Compatible with KP/UNFCCC	Need to divide the developing countries (G77 and China) into several sub-groups. Although formal sub-groups exist (AOSIS, LDCs, OPEC), the G77 and China are likely to strongly oppose the break-up of their negotiating block Intensity targets reduce certainty about environmental effectiveness and complicate implementation

that it can result in surplus emissions and, subsequently, in possible excessively large financial transfers. Neither does the approach take any national circumstances into account. Finally, the resource-sharing concept is likely to meet major policy objections from some key countries, which either do not adhere to a top-down regulation of global commons and the concept of per capita rights (like the USA), or, which, although being part of the developing world, already show relatively high per capita emission levels (like China). Some of these problems can be remedied, for example,

by including national adjustment factors and/or regional allocations of emissions (allowing for a regional redistribution under emission bubbles) and by restricting the eligibility of the least developed countries to participate in emission trading in relation to the certainty about their emission levels (to avoid overselling).¹⁵ Other strengths and weaknesses are summarized in Table VIII.

The strengths of the Multi-Stage approach are its linkages and balanced coverage of different equity principles (capability, responsibility and egalitarian), as well as its flexible concept, with types and levels of commitments adjusted to development levels and offering room for negotiation. In this way, a balance is struck between early participation of developing countries and adjustment to country capacity to take on and implement commitments. Moreover, the approach is well compatible, both with the UNFCCC and the Kyoto Protocol. Its main weakness is probably still the need to divide the group of developing countries (G77 and China). Other weaknesses are the complications resulting from the use of intensity targets, and the limited capacity of this approach to adjust to more stringent targets over time (particularly in the Multi-Stages B and C variants). The problems with the intensity targets might be remedied by either allowing developing countries to trade only after the commitment period (ex-post) or by adopting a dual-intensity target approach (Kim and Baumert 2002), which would also further reduce economic uncertainty.

5. Conclusions

In this article we have described and analysed the implications of a number of alternative Multi-Stage approaches for the differentiation of future climate commitments under two alternative global emission profiles. A major new element to this Multi-Stage approach is the introduction of a composite Capacity–Responsibility index that indeed reflects the key preoccupations of Article 3.1 of the UNFCCC. This index is in particular used as the first threshold for adopting intensity targets for the non-Annex I regions, instead of a single capability-oriented threshold, i.e. per capita income. The analysis of the three Multi-Stage cases shows that:

- For all Annex I countries, in 2025 the reductions in assigned amounts of at least 30–55% compared to the 1990 levels, are necessary to achieve the 550 (CO₂-equivalent) ppmv target and 0–20% for the 650 ppmv target. In 2050, the reductions are at least 70% (S550e) and 40% (S650e). Among the Multi-Stage cases, Multi-Stage C results in the largest reductions on the short-term for Annex I, due to the late entry of the middle- and high-income non-Annex I regions.
- The region South-East and East Asia (including China) plays a key role in the Annex I emission reductions. An early entry of this region in the emission–reduction stage results in lower reductions for the other participating regions (i.e. Annex I regions), since the total reduction needed to achieve the global emissions profiles is now shared with a larger group of countries.

- Participation of the major middle- and high-income non-Annex I countries in reductions is needed before 2025 in S550e, and before 2050 in S650e. For S550e, this implies that countries will start to participate at significant lower per capita income levels than for Annex-I under the Kyoto Protocol (less than 50% of average 1990 Annex I per capita income).
- As far as the emissions for non-Annex I regions are concerned, the results of the Multi-Stage cases are quite sensitive to particular assumptions, such as participation thresholds and global emission profile. No general conclusion for this group as a whole can be drawn. For the S550e profile, the Multi-Stage C case tends to result in fewer reductions for the middle- and high-income non-Annex I regions, while for the low-income non-Annex I regions, the Multi-Stage B case requires the least efforts. For the S650e profile the results of the different cases in the short term (2025) are quite similar due to the late participation of most non-Annex I regions.

When comparing the results of the three Multi-Stage cases with the Per Capita Convergence scheme (PCC2050), the Annex I emissions are found to be largely comparable. However, under stringent stabilisation profiles short-term reductions for the Annex I regions are relatively larger under Multi-Stage. Another distinctive difference between the Multi-Stage and the PCC approach is that under less stringent stabilisation profiles the PCC results in considerable amounts of surplus emission endowments for the low-income non-Annex I regions, which need to be compensated for by lower endowments in Annex I regions and middle- and high-income non-Annex I regions with relatively high per capita emissions close to the world average. Under the Multi-stage approach no surplus endowments occur.

Because the Multi-Stage schemes include the possibility of different types of commitments for regions with different levels of wealth and intensity of emissions, they are probably considered as good candidates for the long-term international post-Kyoto climate architecture that will have to be developed soon. It is a flexible concept that is able to strike a balance between providing structure and leaving room for negotiation. The concept allows for an incremental, but rule-based broadening and deepening of mitigation commitments. In this way, it could open new and clear pathways for addressing the critical issue of the participation of non-Annex I Parties in an international climate regime. At the same time, the approach may face resistance from the G77 for dividing up its group, while the early participation of non-Annex I countries under stringent global emission profiles probably will also encounter resistance – even though participation in emissions trading may turn out to be profitable. Further research into implications of burden-sharing keys and types of commitments, along with an analysis of the costs and co-benefits, will be needed to provide insights into the incentives for participation. Moreover, the design of the Multi-Stage also requires further analyses of the practical aspects of the implications of such schemes.

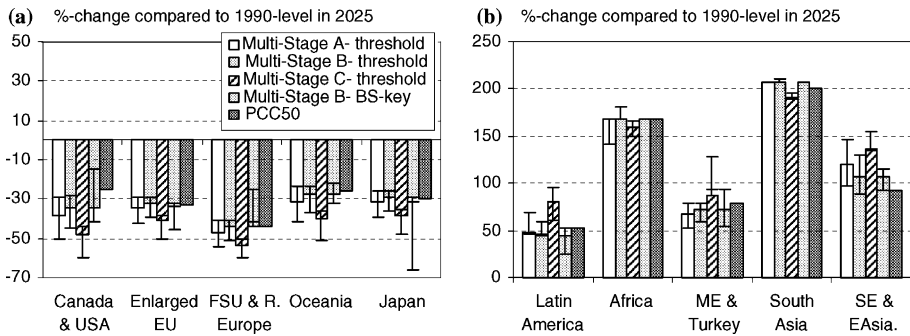


Figure A.1. Robustness of results for the Multi-Stage cases for the Annex I regions (a) and non-Annex I regions (b) under the S550e profile.

Appendix A. Robustness of Results for the Multi-Stage Cases Under the S550e Profile

Figure A.1 shows the robustness of the results for varying the main participation thresholds of Stage 3 for Multi-Stages A and B, as well as the transition constant for Multi-Stage C (first three column bars). More specifically, for Multi-Stage A, this is 80–120% of the world average per capita emission threshold, for Multi-Stage B, the CR-threshold of 10–15 and for Multi-Stage C, TC values of 50–100. The figure shows changes in the parameter values for the middle- and high-income non-Annex I regions to affect the outcomes, while Multi-Stage C still leads to the lowest reductions. For the low-income non-Annex I regions, changes in parameter values for Multi-Stages A and B do not affect the outcomes on the short term, since they do not yet participate in the emission-reduction stage. For Multi-Stage C, the effect of changing the TC value is also small. For the Annex I regions, Multi-Stage C remains the one with the highest reductions on the short-term. Depending on the parameter settings of Multi-Stages A and B, now PCC50 may currently no longer be the one with the lower reductions. In general, the difference between the outcomes of Multi-Stages A and B are small.

Another main parameter is the burden-sharing key in the emission-reduction stage. Changing the default burden-sharing key, per capita emissions to per capita income leads to higher reductions for the OECD regions, in particular, Japan, the US and Canada, and lower reductions for FSU and the middle- and high-income non-Annex I regions (shown in the fourth column bar for the Multi-Stage B case only). A burden-sharing key based on total emissions leads in general to the opposite situation (also shown in the fourth bar).

This analysis shows that the future emission reductions of the three Multi-Stage cases depend just as much on the Multi-Stage case chosen as on the exact parameter values used. The most important parameters are the threshold levels and the burden-sharing keys.

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Notes

1. More specifically, the approach divides the developing countries (non-Annex I) into three categories. The first includes countries with high income or high emissions; the second, countries with intermediate income or intermediate emissions, and the third, countries with low income or low emissions (Blanchard et al. 2001). For each of these categories the approach prescribes emission pathways that result in a stabilisation of emissions from respectively 2015, 2025 and 2030 onwards.
2. The complex problem of assessing the costs, benefits and co-benefits of the different regimes for the different regions of the world is not addressed in this article; preliminary elements of such an analysis can however be found in Criqui et al. (2003); van Vuuren et al. (2003) and den Elzen et al. (2004b).
3. The ‘CO₂-equivalent concentration’ is a measure of radiative forcing of the set of the six greenhouse gases covered under the Kyoto Protocol (i.e. carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF₆)), hereafter referred to as ‘Kyoto gases’, expressed in terms of the CO₂ concentration that would result at the same level of (additional) radiative forcing.
4. The two stabilisation levels were chosen so as to represent cases of early and stringent mitigation, for example, to meet the EU long-term climate target of limiting global average temperature increase to a maximum 2 degrees Celsius above pre-industrial levels (European Council 1996), versus a less stringent profile for global greenhouse gas emissions.
5. A demonstration version of FAIR 2.0 can be downloaded from: <http://www.rivm.nl/fair>.
6. However, in den Elzen et al. (2003) some qualifications of this scheme are indicated.
7. The difference in the remaining emissions, i.e. global emissions of profile minus the total emissions of all regions in Stages 1 and 2 at times t and $t - 1$.
8. Obviously, there is no certainty that this will happen, but this also holds for the assumption made in this analysis that the Kyoto Protocol will enter into force. However, as pointed out in the introduction, it is hard to conceive any global climate regime compatible with stabilising GHG concentrations at low levels, such as 550 ppmv-equivalent, if the US would decide to stay out until after 2012.

9. GDP levels of different countries are usually compared on the basis of conversion to a common currency using Market Exchange Rates. However, this is known to underestimate the real income levels of low-income countries and introduce a bias in the measure of regional GDP and economic growth. Therefore, an alternative conversion has been developed on the basis of purchasing power parity (PPP).
10. The emissions during Stage 2 are calculated as: $E(t-1) + V_0 \times [1 - [(t - t_0)/LTS]]$, where $E(t-1)$ are the emissions of the previous year, t_0 the start year, LTS the length of the stabilisation period and V_0 the average increase in the emissions before the CR-threshold is passed.
11. The share of a region r in the total emission reduction is calculated as $X_r = (E_r * pcE_r)$ divided by the sum of X over all regions, with E_r representing the total emissions and pcE_r the per capita emissions. In this way, two regions with equal per capita emissions but different total emissions make the same relative reduction effort compared to their emissions.
12. The option of the burden-sharing key based on emissions, which implies a flat rate reduction in Stage 3, does not seem adequate, as it will not result in a convergence of per capita emissions over time. It will also punish the countries that have entered the transition stage at a relatively low per capita emission level.
13. In our model, IET is more cost-effective than CDM. This is due to the CDM project basis, which only allows the assumption that a limited amount of the abatement potential is operationally available on the market, whereas full access is assumed for IET. The assumption for IET is made because the adoption of national commitments requires national emission monitoring and registration systems to be elaborated that will function comprehensively at the national level. Adopting commitments also helps in identifying emission reduction opportunities (Criqui et al. 2003; van Vuuren et al. 2003).
14. In principle, this is only true when there is no global cap and no swing producers of reductions.
15. In principle, the PCC approach could be detached from the egalitarian concept of equal human entitlements to the use of global commons, by providing countries allowances instead of rights but this seems hard to conceive given the ideological origins of the concept.

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